98

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A STUDY ON THE USE OF FIGHTER AIRCRAFT TO PROVIDE A ZERO G ENVIRONMENT IN SUPPORT OF SPACE MANUFACTURING EXPERIMENTS

By Space Simulation and Experiments Office
Manufacturing Engineering Laboratory

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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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ABSTRACT

Previous space flight development efforts have included the need for zero gravity test conditions. Early medical research used fighter aircraft for human and animal experiments; early NASA projects employed the KC-135 for engineering and functional spacecraft testing and for valuable contributions to astronaut procedural training.

The Marshall Space Flight Center's mission assignments in space manufacturing and construction require a locally available, low cost, zero g testing method with time/cost variables between the present drop tower and orbital flight. Such a facility can best be provided by minimal conversion of a fighter-type aircraft.

Available possible aircraft include the T-33, the T-38, the F-94C, the F-104, and the F-4. The T-38 should be considered the optimal aircraft for conversion; it can produce continuous zero gravity parabolas lasting 1 minute and 20 seconds. For initial conversion, the T-33 aircraft represents the best choice since it is more available and can be modified at a lower cost than the T-38; it is capable of a maximum single parabola time of 35.8 seconds.

Removable pods equipped with instrumentation for monitoring of tests under zero g flight are recommended. These pods would be designed to fit available space within the aircraft or fasten to existing attach points external to the aircraft.

Costs involved in modifying and operating the T-33 aircraft for zero g experimentation were estimated.

Attempts were made to obtain comparative operating cost data for the KC-135 aircraft now in service for zero g testing. This information is available from the Air Force but is considered classified.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I. CONCLUSIONS AND RECOMMENDATIONS

It is concluded from this study that fighter type aircraft can be modified to provide a true zero gravity environment within which space manufacturing studies can be made. It is further concluded that basic studies can be conducted, within the modified aircraft, which would support the development of space manufacturing experiments now under consideration.

The T-38 model aircraft was identified as being the optimal aircraft for conversion; however, it is recommended that initial consideration be given to converting the T-33 model aircraft since it is readily available and could be modified at a lower cost.

SECTION II. INTRODUCTION

Past space flight experiences have clearly shown that reliability and results are enhanced through use of special ground simulation and testing techniques. Neutral buoyancy zero g simulation, used extensively for the first time in training astronaut Aldrin for Gemini, dramatically demonstrated the results gained over previous flights through the use of this technique. (See Reference 1). For astronaut procedureal training, where object-to-object (external) zero g representation is the required relative value desired, this method of water immersion is an adequate technique. Of course, in this case, all the ordinary gravity-bound conditions are met (i.e., objects develop a weight equal to their mass times standard 1 g acceleration they are restrained from relative movement with an upward force equal to their weight). The only difference between neutral buoyancy simulation, or so-called "zero" gravity simulation and the usual earth gravity conditions is that the gravity counterforce (upward restraining force) is developed on the exterior surfaces of a submerged body. Under normal conditions, the gravitational counterforce is applied at specific planar reaction surfaces such as the shoe-floor or chair-seat contact areas. Under water immersion "zero" gravity simulation, the body experiences the supporting counterforce over its entire surface and throughout the water medium, independent of any planar reaction surface. (See Reference 2). Thus, neutrally buoyant objects "float" and the external body-to-body situation contains a high degree of similarity to the free body "zero" gravity situation during orbital space flight.

While water immersion is a suitable technique for astronaut procedural training, it is totally unsuitable for other types of zero g studies. For example, the action of liquids within tanks during orbital zero g conditions cannot be studied using this technique since the internal tank liquid-to-tank condition would be the same regardless of the method of external tank wall support. (See Reference 3). Physical, physiological, and medical processes which require true relative zero g can presently be studies only if some method can be found to completely remove the restraining counterforce that resists free fall. In this condition the free body acts under the influence of gravity and its own inertia and is in a state of free fall or virtual weightlessness, exactly equivalent to the orbital flight condition.

Early medical research chose the high speed fighter aircraft in which to develop zero g since their requirements were for true relative zero g on human or animal test subjects for as long a period of time as possible. (See References 4 and 5). As space flight progressed, on-board space was utilized for research purposes where the experiment priority was high enough and the high costs could be afforded. (See Reference 6). Zero g testing also evolved into large scale procedural development and training aids for the astronauts. KC-135 aircraft were converted for this use; these aircraft plus neutral buoyancy methods proved invaluable in the development of space flight capabilities. The short 10 to 20 second periods of true relative zero g available from the KC-135 were uniquely complimented by the unlimited time of simulated zero g available from immersion simulation. The limitations of these techniques were easily overcome especially when testing human procedural problems and solutions.

A recent example of the brilliant use of simple, low cost zero g testing is found in the work of Dr. Thomas R. Kane, Professor of Applied Mechanics, Stanford University. (See Reference 7). Dr. Kane analyzed the problem of reorientation of astronauts by means of limb movements through application of the methods of classical theoretical mechanics. This complex analysis was experimentally verified by Dr. Kane using a trained gymnast on a trampoline. Such a system afforded a true relative zero g time of about 2 seconds. Commands for executing the limb movement reorientation maneuvers were given after the gymnast became airborne from the matt. By this method no reaction could be gained from the matt. Photographic data from the experiments clearly demonstrated the validity of the theoretical analysis.

The practical achievement of extended zero g conditions within the atmosphere can be accomplished only through special flight techniques used with high speed aircraft. The aircraft can be flown in such a manner to allow free fall of objects carried inside. The aircraft requirements are that the required free fall velocities be precisely attainable and that the test object be relieved of the dynamic air loads developed at such speeds.

Now that space flight is a proven reality, our needs naturally turn toward the profitable uses of this unusual tool. The requirement for vastly increased knowledge relating to space manufacturing and construction processes represents a highly probable future involvement for the Marshall Space Flight Center. Thus, there exists a critical need for MSFC to develop locally based, immediately available, low cost, true zero g testing and simulation techniques. The most logical answer to these needs rests with the adaptation of modern fighter aircraft as a test-bed for providing a true relative zero g environment in which to conduct space manufacturing experimentation.

SECTION III. ZERO G TRAJECTORY ANALYSIS

The basic physics and equations of motion which describe zero g trajectories for aircraft have been presented previously. (See References 5, 8, & 9). They are updated here to include data on the latest available aircraft and to allow ready reference.

The single basic requirement for kinematic production of zero gravity is that the aircraft achieve a vertical change in velocity equal to the gravity field acceleration in which the craft is located. This must be accomplished without adding spurious accelerations in other than gravity field plane.

This requirement is totally in the vertical plane. This means that a craft loosed vertically with some initial velocity (V_o) must lose a velocity increment (-gt) per unit time on the upward portion of the trajector until the initial velocity is reduced to zero. It may then continue to accelerate downward gaining vertical velocity on the downward portion of the flight. An aircraft cannot follow such a stylized vertical flight path. The aircraft requires that the relative air vector always be directed more or less rearward along its longitudinal axis. To maintain this aerodynamic requirement in a vertical trajectory, the aircraft would be required to rotate instantaneously 180^{o} at the peak of the trajectory. Since the aircraft cannot do this, it must begin its zero g flight with a small horizontal component of velocity which remains unchanged throughout the zero g maneuver. Since the vertical velocity component reduces to zero at the apex, the horizontal component remains as the minimum maneuver speed at this point. The maximum flight speed combines with this constant horizontal component at entry and exit to define the entry and exit angles. (See Reference 8).

A typical parabolic trajectory is shown in Figure 1. A spiraling slight diving entry is used to gain airspeed (Point a to b). Point b indicates the initiation of pull up, and accelerative overload from Point b to c. Point c indicates the beginning of zero gravity, the achievement of entry velocity and entry angle. On the upward limb, the vertical velocity continually reduces toward zero while the horizontal velocity remains constant and equal to the flight velocity at Point d, the peak of the trajectory. Point d to e represents the descending or diving portion of zero gravity flight where the aircraft vertical velocity component is continually increasing. During this part of the trajectory, the flight acceleration and the local gravity acceleration are all in the same direction. Point e represents the end of the zero gravity condition and the beginning of diving pullout to level flight.

The equations which relate the pertinent variables of velocity, acceleration, attitude change, and zero gravity time are:

The total time (T) of the zero gravity condition:

$$(1) \quad T = \frac{2\ V_o\ \sin\alpha}{g}$$

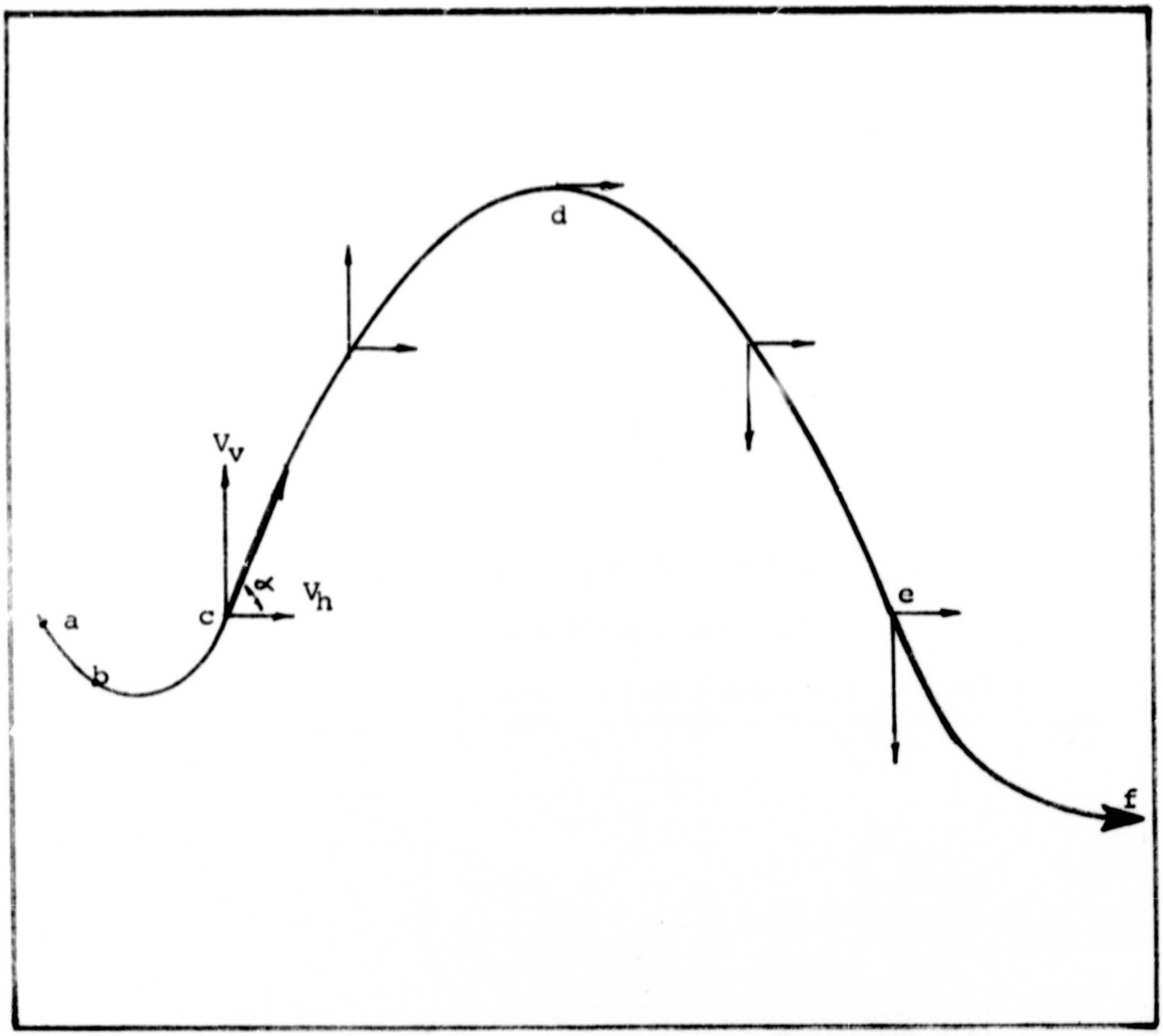


Figure 1. Typical Velocity Vector Components During Zero-G Profile

where: V_o = Maximum flight (entry) speed

α = Angle of entry

g = Local gravity constant

The initial entry angle:

$$(2) \qquad \alpha = \cos^{-1} \frac{V_h}{V_o}$$

where: V_o = Maximum flight (entry) speed

V_h = Minimum flight (horizontal) speed

The maximum altitude and the change in altitude:

$$(3) \quad H_{max} = H_o + 4.026T^2$$

where: H_o = Initial altitude at entry (Point c Fig. 1).

T = Total time of zero gravity

Figures 2, 3, 4, and 5 show the relationship between the variables which control the zero g parabola. (See References 8 and 9).

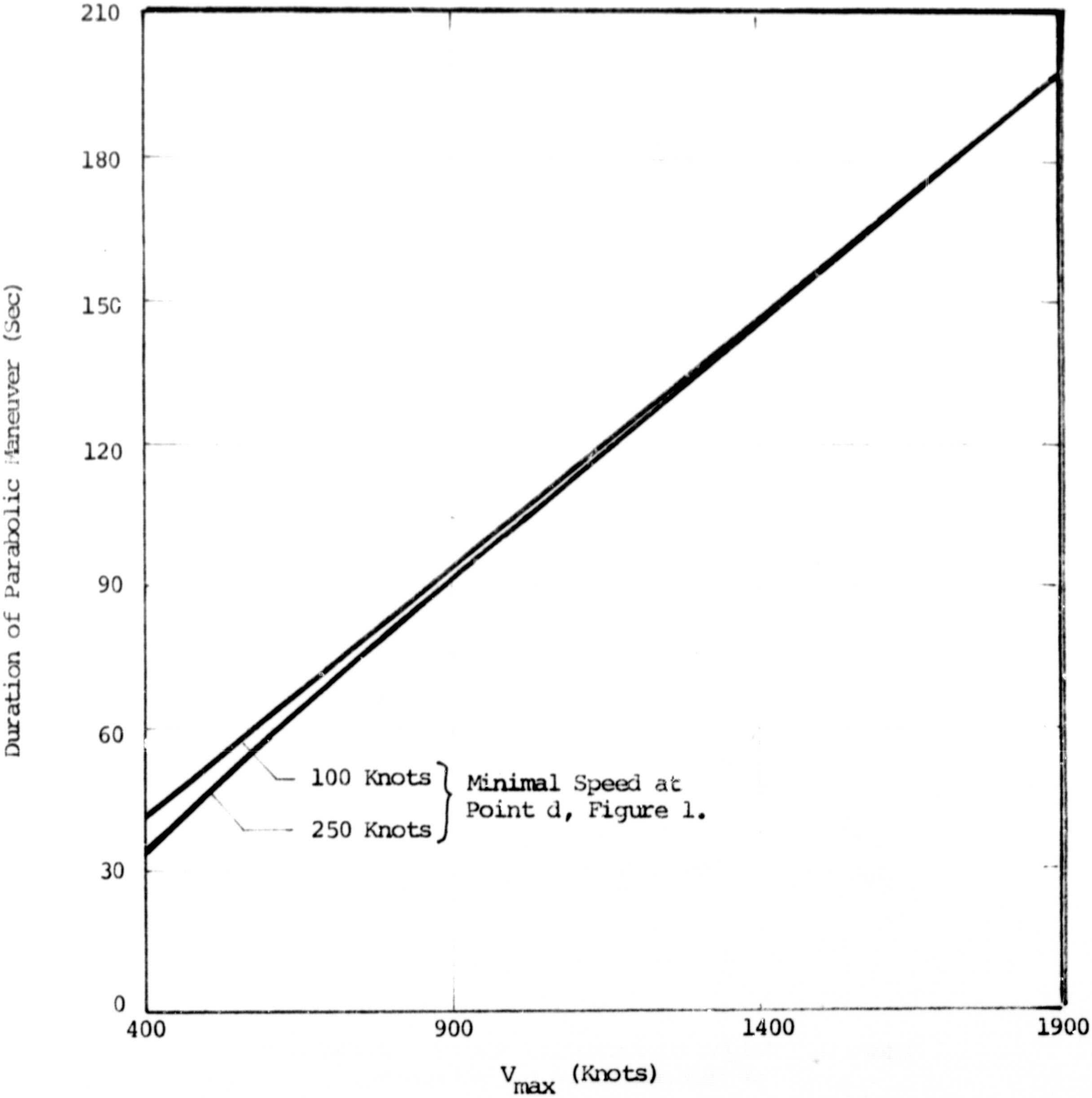


Figure 2. Duration of Zero-G State vs. Maximal and Minimal Speed.

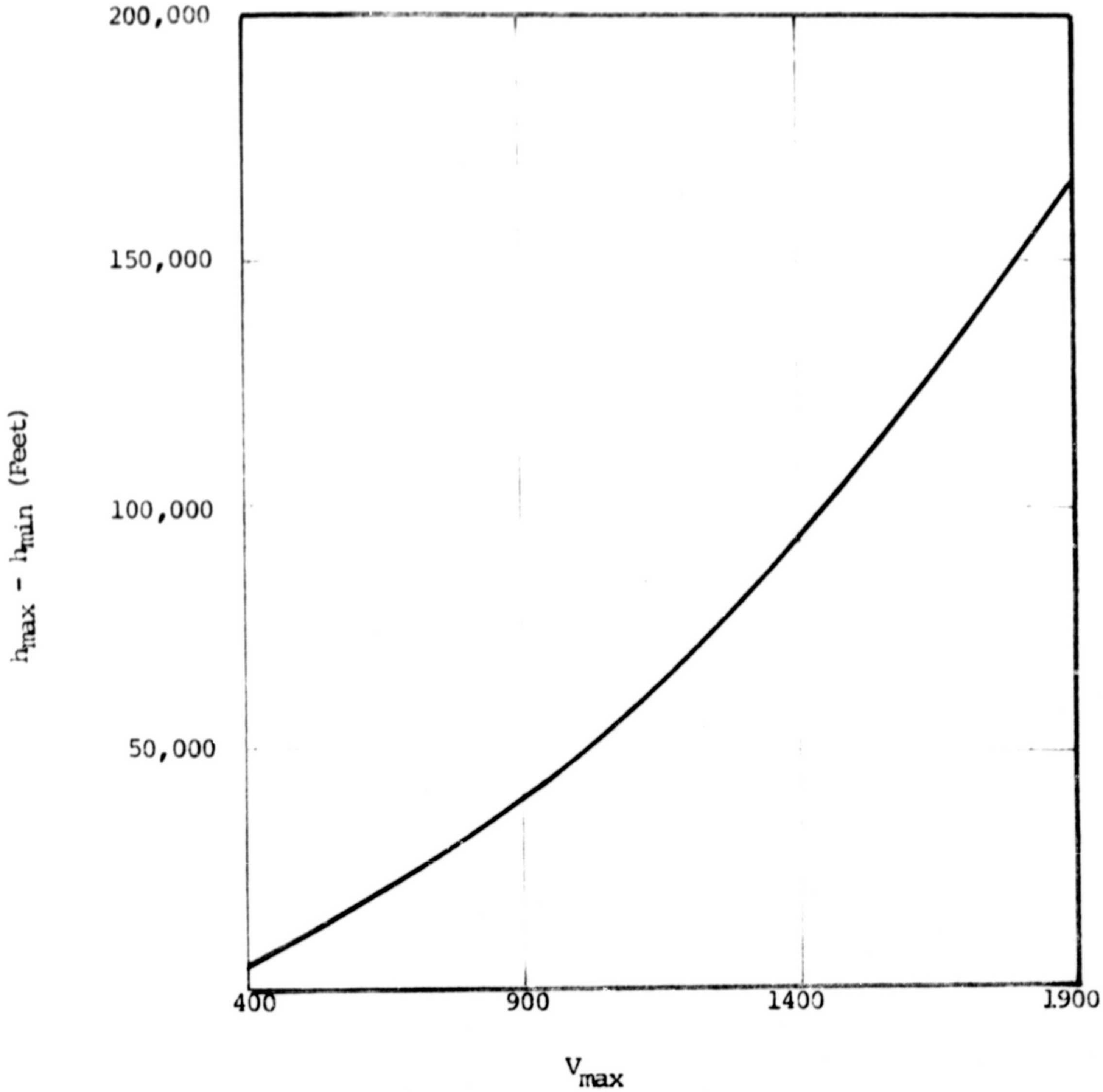


Figure 3. Height of Parabolic Arc vs. Maximal Speed For Minimal Speed of 100 Knots.

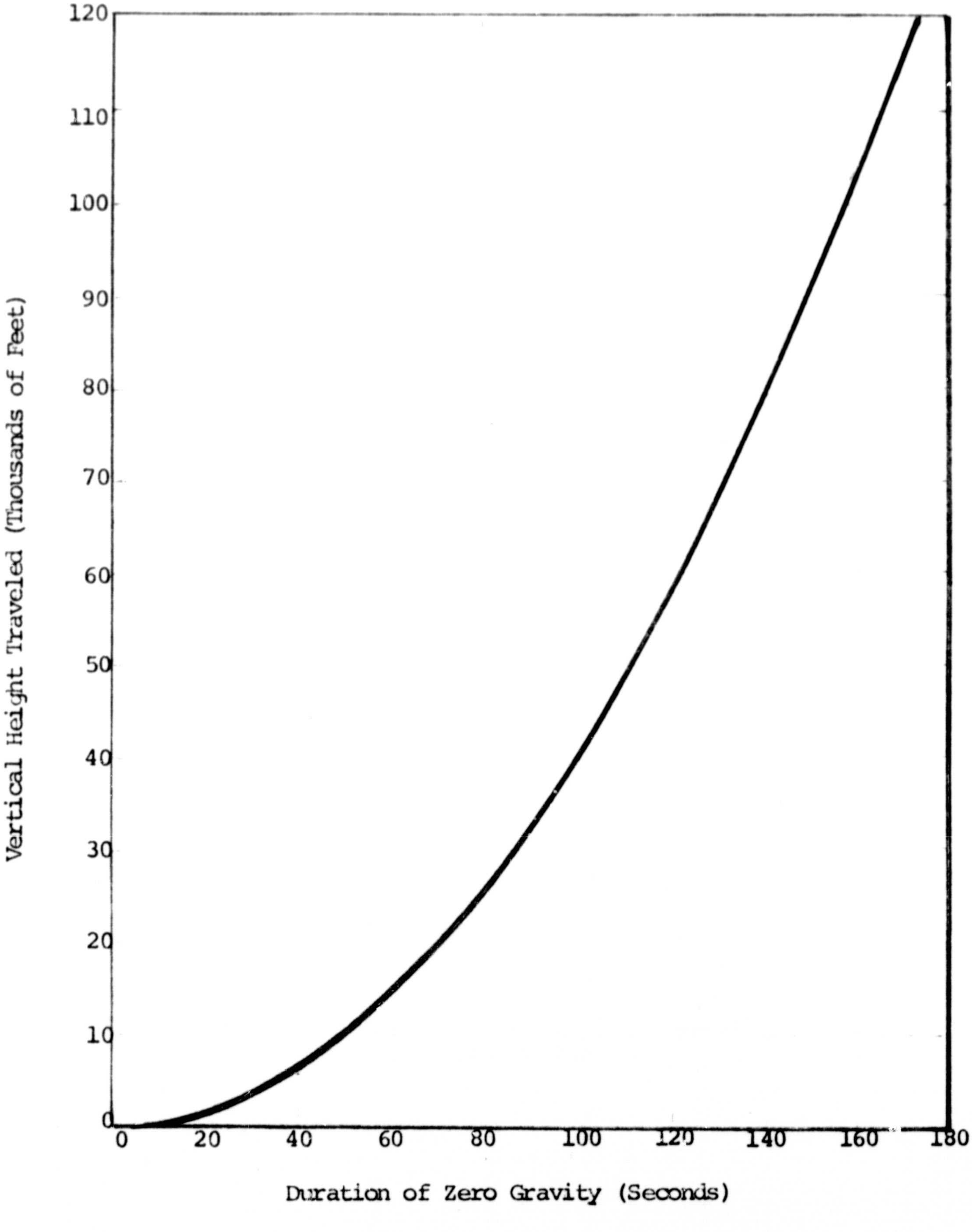


Figure 4. Total Duration of Parabolic Flight vs. Vertical Height Traveled

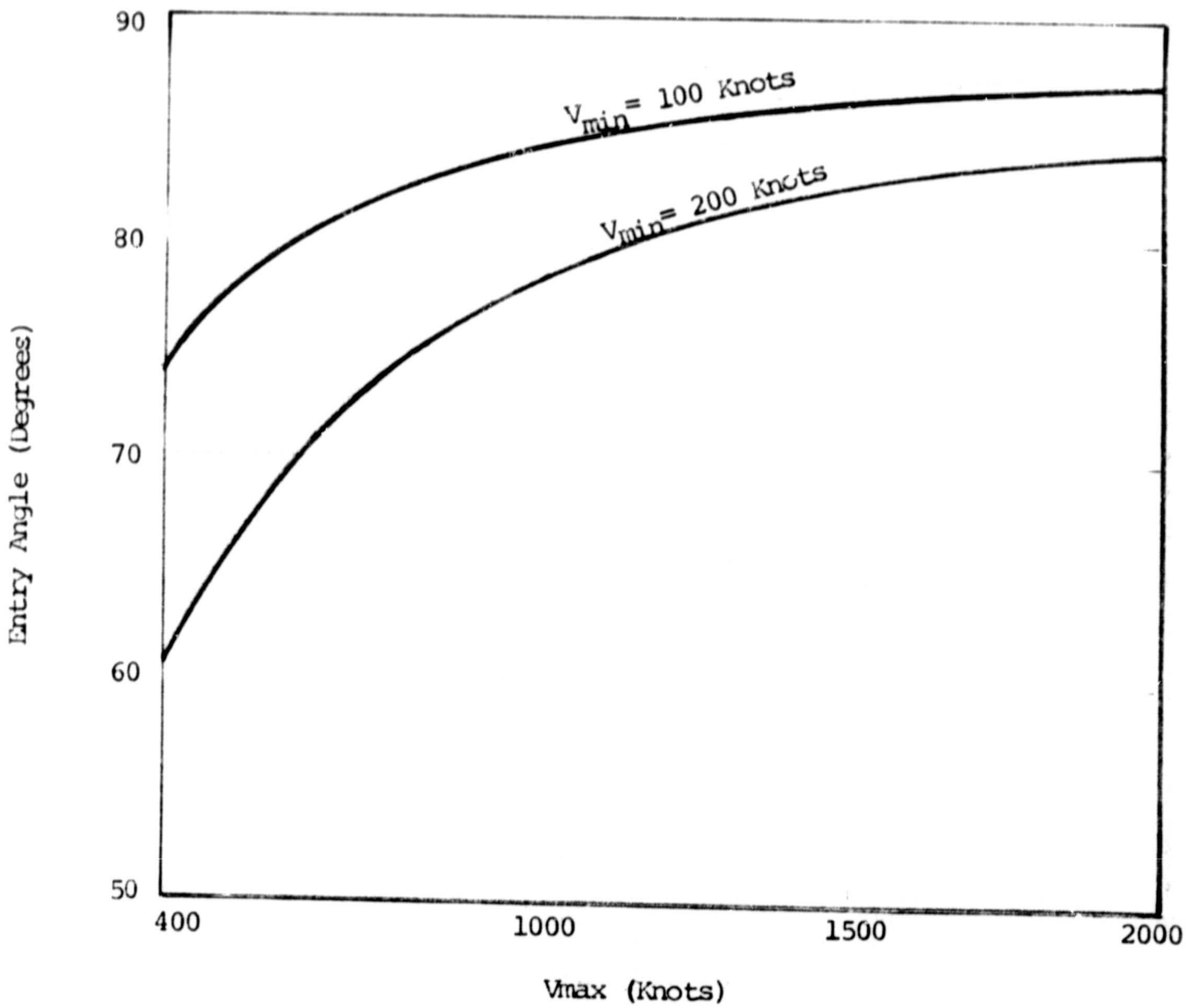


Figure 5. Optimal Entry Angle vs. Minimal and Maximal Speed.

SECTION IV. POTENTIALLY USABLE AIRCRAFT AND RELATED PERFORMANCE CHARACTERISTICS

A. Basic Aircraft Requirements

The basic requirements for the zero-g aircraft are:

1. The aircraft should have as high a maximum speed as possible.

2. The aircraft should have as low a minimum control speed as possible.

3. The aircraft should have no systems which are adversely affected by zero-g maneuvers.

4. The aircraft should have adequate space and weight carrying ability for the experimental equipment required.

5. The aircraft should have no major engine systems, or airframe problems which would compromise flight safety throughout the full dynamic range of flight conditions to be encountered during zero-g flights.

The requirement for high entry speed and low minimum control speed results because the difference between these speed values determines the maximum zero-g time available. It should be noted that minimum control speed is not the ordinary stalling speed of the aircraft. During the zero-gravity maneuver no lift is required of the lifting surfaces since there is no effective weight being applied by the aircraft. Lifting surfaces are operating at or very near a zero degree angle of attack. At this angle of attack, with essentially zero wing loading, the "stall" speed occurs at zero relative air velocity. The minimum control speed required may be more or less than the ordinary 1-g stalling speed for a particular aircraft.

A large number of possible zero-g induced systems difficulties have been considered in preparing this report. The most probable difficulties with the aircraft are in those systems in which a liquid phase is present.

1. The Fuel System

During a 60 second zero-g maneuver, modern fighter aircraft will consume from 5 to 25 gallons of fuel. Normal aircraft fuel systems depend on a positive g-loading to orient the fuel for boost pump and engine pickups. Liquid tension forces during zero-g are not sufficient to maintain the fuel flows for the quantity of flow listed above from the floating fuel mass in the tank toward the liquid pickup point. Therefore, unless the fuel system is especially modified for zero-g use, erratic engine operation and flameout can occur after the fuel already in the lines under positive pump conditions is consumed.

2. The Lubrication System

Those oil systems which are diagramatically similar to the fuel systems, those which have gravity-oriented pickup points, will have potential difficulties under zero-gravity conditions. The major differences between fuel & oil systems arise due to the susceptibility of the particular engine to oil starvation and the permanency of this effect after normal gravity returns. Each aircraft and

engine combination will vary widely from no modification necessary to modification for a positive displacement oil resorvoir-supply system.

3. The Hydraulic System

The action of the hydraulic system will vary with the particular aircraft. Most of the early aircraft will have mechanical primary controls with hydraulics for boost only: these earlier systems will not be considerably troubled by undergoing up to 60 consecutive seconds of zero gravity flight. Later aircraft have much more complicated hydraulic systems which comprise the full flight control system. These systems are subject to fluid reservoir and fluid pickup pump cavitation problems similar to the fuel system problems described above. Additionally, most modern aircraft hydraulic flight control systems are sensitive to inclusion of vapor within the positive pressure sections, especially in the actuators of the system. In order to avoid this problem, vapor-oil separators are usually a part of the hydraulic system. It would be necessary to evaluate the effect of zero-gravity on the particular modified zero-g hydraulic system and to certify that no additional vapor was being injected into the system under zero-gravity operation. Modification of these vapor-oil separator systems therefore must be considered in addition to the hydraulic fluid pickup.

4. Liquid Oxygen Breathing Systems

The more modern jet aircraft are equipped with LOX converter-containers as the reservoir for crew member breathing oxygen. These containers depend on gravity and orientation to separate the vapor-liquid phases. It is possible that the "liquid float" condition observed during zero gravity will cause improper pickup and feeding of LOX from the container-converter.

There also may be zero-g problems introduced in the LOX heat exchanger section downstream of the LOX container. This heat exchanger operates under normal g loading to positively vaporize the liquid and bring the resulting breathing GOX up to a proper temperature for crew member use. Under zero-g conditions, the "float" may relieve the LOX droplets from contact with the walls of the downstream converter heat exchanger and result in delivery of liquid LOX or gaseous, breathing oxygen at lower than acceptable temperature.

Converters for orbital flight crew use have been built and also relatively simple modifications may be able to be used to eliminate this problem

5. Special Systems Problems

Each aircraft being reviewed for possible use should be carefully scrutinized for any specific aircraft systems or zero-g induced flight safety problems other than the general problems listed above. For instance, the fuel control systems on the General Electric J-79 series engines, which currently power the F-104 and F-4 aircraft, is actually a complex fluidics system which has potential dangers under zero-g conditions. This fuel sontrol systems uses the fuel itself internally as a fluid control and fluid power medium. External to the fuel control, the fuel is routed to power the variable stator stages in the engine compressor section, routed to the engine fuel oil heat exchanger, and

finally, is routed to the engine combustor cans for its original purpose as combustible fuel. Vapor entrained into this fuel system due to zero-g maneuvers may have unpredictable results, results which may reduce the reliability of post zero-g engine operations.

B. Considerations of Available Aircraft

This report considers five aircraft as possible aircraft for use in supporting MSFC zero-g simulation. These aricraft types are the T-33, T-94C, T-38, F-104, and F-4H. The T-33 and F-94 have been previously used for zero-g support of early medical studies by the USAF, School of Aviation Medicine, San Antonio, Texas, and by the Space Biology Branch of the USAF Aeromedical Field Laboratory at Holloman Air Force Base, White Sands, N. M. [10]. The results of using these aircraft have been previously published by these medical researchers, as well as their estimates of the potential value of using the F-104 aircraft in this type work. These studies were accomplished in the 1950's. During this time the F-104 was in experimental service only; the T-38, and F-4 were not available. This study has included as much additional practical information as possible that has been gained from operational and special service use of the newer aircraft since these medical reports were made. This information is included so that evaluation of all potentially useful available aircraft may be made at this and at any future date.

1. <u>The T-33 Aircraft</u>

The T-33 aircraft [12] is a two seat, single engine, turbojet powered aircraft. It was built by the Lockheed Aircraft Company as a growth version of the original F-80 aircraft to be used extensively by all U.S. Military Services. Its use was primarily in administrative, fighter transition, and student trainer capacities. It is still in service in small numbers in the administrative flight role. Large numbers have been retired from the training commands and have been replaced by more modern trainers such as the T-38.

The T-33 has a maximum theorectical zero-gravity time of 35.8 seconds. Its flight trajectory will include a maximum true air speed of 350 knots at entry and exit, and a minimum speed of 100 knots at the trajectory peak.

The fuel system must be modified in order to insure positive zero-g operation. The J-33 centrifugal compressor is known to be unusually insensitive to interruptions in oil supply. Even though momentary oil pressure losses can be expected without oil system modifications, no significant problems are expected to occur from this.

The crew members' breathing oxygen is from a gaseous oxygen storage and supply system. No problem is expected with this system.

All aircraft primary flight control systems are mechanical. Hydraulic boost is applied only to the aileron system. The dive brakes are also hydraulic powered and can be expected to be used normally following termination of zero-g and during pull-out of the dive. Small fluid volume usage should be expected through the aileron boost system during the zero-gravity flight and no problems are at present predicted for the unmodified T-33 hydraulic system.

Previous usage of the T-33 for zero-gravity investigations has been reported by Gerathewohl and Von Beckh [10, 11]. These reports indicate regularly achieved zero-g time of 20-25 seconds. In addition slight lateral stability problems and fuel flow interruptions were also reported. No modifications were reported since these investigators adopted the F-94C as a more useful vehicle.

2. The F-94C Aircraft

The Lockheed F-94 aircraft is a growth version of the F-80, T-33 series aircraft. It was built to carry a pilot and radar observer primarily for an air defense interceptor role. This aircraft has been totally retired from active service and, because of the maintenance difficulty associated with an aircraft not being actively used, is not being considered as a practical candidate aircraft. However a great amount of the previous work and the longest zero-g fighter aircraft service was obtained with the F-94. For this reason the F-94 is mentioned here.

The F-94 was equipped with a centrifugal compressor engine and an afterburner. Since the aircraft had a higher limiting mach number than the T-33 the entry speed was moved up to 425 knots and the maximum practical periods of weightlessness were increased to 40-45 seconds. Less lateral stability problems were also noted than when using the T-33.

3. The T-38 Aircraft

The Northrup T-38 aircraft is a growth version of the N156F or F-5 NATO fighter aircraft. The T-38 carries two crew members with a primary mission of advanced jet training for USAF students.

The T-38 has two small General Electric axial flow turbojet engines each equipped with afterburner. It can reach a maximum mach number of 1.4 to 1.5 in level flight above 20,000 ft. With this maximum speed it can achieve a zero-g time per parabola of 1 minute and 23 seconds. This aircraft is lightweight, is relatively easy to maintain, has the safety aspect offered by two engines, and can operate easily from shorter runway lengths. It is in current service in the USAF in great numbers. From an over-all standpoint the T-38 offers the maximum practical value as a zero gravity support test aircraft.

4. The F-104 and F-4 Aircraft

The Lockheed F-104 and the McDonnel F-4 aircraft are both available in two seat versions. Both aircraft offer maximum speeds in excess of mach 2.0; therefore, both aircraft theoretically offer more than 2 continuous minutes of zero-g time per single parabola. Both aircraft are equipped with the General Electric J-79 axial flow turbojet engines with afterburner. Both aircraft have highly sophisticated full flight hydraulic control systems which will have to modified for zero-g use along with their fuel and LOX breathing systems.

Earlier studies have indicated a desire to use the mach 2 + speeds of the F-104. Squadron service with these high mach (F-104 and F-4) aircraft has

become a reality since these recommendations were made. This practical service, especially the special service use in developing attack procedures for use against ultra high flight reconnaissance aircraft of the U-2 type, has shown some problems not anticipated by the early medical researcher in making this recommendation for zero-g use.

First of all, these maximum speeds of mach 2 are limited by dynamic air loading of the hot turbine section (nozzle diaphagm). This limit specifies a loading equivalent to an indicated airspeed of not more than 750 knots. This IAS or less is coincident with mach 2.0 + only above 33,000 + feet. Therefore pull-up altitudes for the zero-g parabola must begin above 33,000 + feet. From the trajectory analysis presented the change in altitude expected from this speed will be at least 30 to 40,000 feet. During the peak altitude of 65 to 80,000 feet several undesirable conditions will be encountered: (1) aerodynamic control will be minimal, and (2) engine airflow near the peak will not be sufficient to maintain idle engine operation without overheat and the engine may have to be shut down. Aerodynamic control could be replaced with a reaction control system and a small rocket engine could be installed. Both of these modifications have been done to produce the NF-104 space trainer aircraft now being used at Edwards AFB-(NASA) Aerospace Test Pilot School.

There is also a certain stability problem with the F-104. In order to solve the aerodynamic problems attendant with very high mach numbers, the designers of the F-104 compromised on a design which is aerodynamically unstable. The required flight stability of this aircraft is adequately replaced by a three axis electronic stabilization system. The pilots handbook [13] continually warns the pilot against placing negative g-loading on this machine. These warnings are emphasized with flight at high mach numbers. Since the aircraft is structurally capable of light negative g-loading, this limit can be deduced as a stability derived limit.

The interaction of the basic aerodynamic instability of the airframe with the electronic stability control system of the F-104 during a maneuver as unusual as the zero-g parabola cannot be adequately predicted. It should be checked by extensive consultation with the designers. It is even possible that for routine zero-gravity use, the F-104, and possibly other very high mach number aircraft, should be placed through a comprehensive special flight test program.

It is doubtful whether the advantages to be gained from modifying these very high mach number aircraft would be worth the cost, especially since the T-38 can be used at much less expected modification and total cost for zero-g times longer than 1 minute. Presently, mach numbers above M 2.0 appear to offer an unprofitable transition between aircraft and spacecraft when projected for zero-gravity use.

C. Recommended Aircraft for Initial Use

From considerations of cost, availability, maintenance, and projected usefullness it appears that the T-33 and T-38 aircraft offer potential value as support aircraft for MSFC studies in space processing, maintenance, construction, and manufacturing. The T-33 is both available, in surplus, and

has maintenance parts available. The T-33 is also still in squadron use. The T-33 will yield 30 seconds of single parabola zero-g time and it is the lowest cost, immediately available option. The T-38 will yield over 1 minute per parabola and should be considered the optimum aircraft for such service.

Pertinent performance characteristics of the various aircraft discussed in Section III are given in Table I.

Type Aircraft	Minimum Speed V_h (Knots)	Entry Speed V_o (Knots)	Starting Altitude H_o (Ft.)	Maximum Altitude (Ft.)	Angle of Climb (Degrees)	Zero-G Time (Seconds)
T-33A	100	350	18,000	23,600	73° 20'	35.8
F-94C	100	450	18,000	27,120	77° 10'	47.6
T-38	100	800	25,000	52,900	82° 50'	83.3
F-104B	100	1100	35,000	80,100	84° 59'	117.0
F-4	100	1200	35,000	100,000	85° 10'	127.0

Table I. Characteristics of Optimal Flight Parabola for Different Aircraft

SECTION V. T-33 AIRCRAFT MODIFICATIONS

There are several areas in the T-33 aircraft that can possibly be converted to experiments package use. These modifications are discussed in this section. Costs are estimates only, and a more precise definition of the requirements will be necessary before final costs can be accurately determined. Depending on this variable, the costs may increase or decrease.

A. The Nose Compartment Position (Item A).

The compartment forward of the command pilot contains navigation electronics, batteries, inverters, antennae, and other equipment. For a special zero-g aircraft, some of this equipment may be removed so that permanent zero-g flight instrumentation or zero-g experiments instrumentation can be installed. Suggested for removal are the ARN-12 receiver, the ARN-18 receiver, and the APX-25 receiver. Four zero-g flight instrument boxes can be added permanently in the available volume.

B. Wing Tip Pod Modifications (Item B).

Each of the wing tip pods normally carries 230 gallons of fuel. With low flight time and practically no radius of action requirements, these pods can be permanently emptied and modified for experiment and experiment support equipment. Access doors can be cut into the pods, the fuel baffles and other fuel associated items removed, and required equipment support stations be designed and affixed. Equipment can then be installed. Existing accessways through the wings are of sufficient size for electrical connections to the pods.

Each wing tip experiments pod could safely carry up to 800 pounds of payload (balance will be required).

C. The Second Pilots Seat Area (Item C).

The rear pilot seat, stick, instrument panel, radios and other equipment can be removed. An experiments pod can be designed to fit this area. The maximum possible load in this area will depend upon how it can be distributed and supported, and upon the structual supports and modifications that can be provided. It is anticipated that an 800 pound payload capability will result from this modification.

D. The Baggage Pod (JATO Area) (Item D).

A redesigned travel pod can be installed near the present position. The loading here will be dependent upon the JATO hook designs. The width and length of this pod can be greater than the present pod, but the depth is limited to approximately the same (11 to 15 inches). The maximum weight of the payload expected here is 300 pounds.

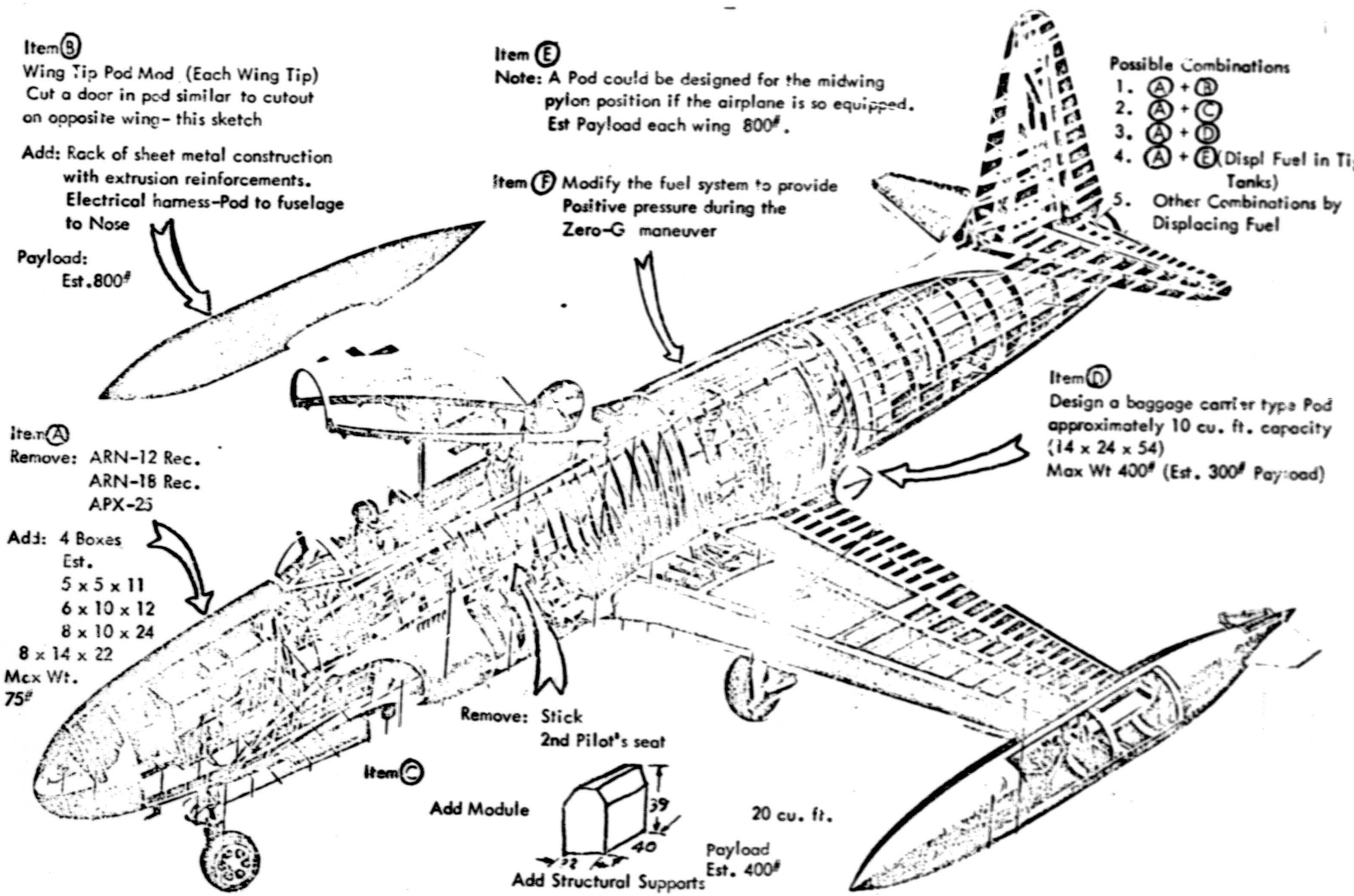


Figure 6. T-33 Aircraft Zero-G Modifications

C. M. Ellis 11/15/68
Rev. 11/19/68

E. Midwing Experiments Pod (Item E).

Some T-33 aircraft have a mid-wing hardpoint installed. This was designed for use of pylon tanks and for bomb practice. If the aircraft has this hardpoint, it is feasible to design and install a mid-wing experiments pod for each pylon. These will be capable of carrying 1000 pounds each (balanced loading), less the pod weight.

F. Space and Weight Combinations Available Simultaneously.

The space and weight capacities discussed previously are not all possible simultaneously. The possible combinations are:

1. A + B
2. A + C (displace fuel in tip tanks as required).
3. A + D
4. A + E (displace fuel in tip tanks as required).
5. Other combinations can be used by displacing fuel as required, such as A + B + C + F.

The volumes available and cost estimates for each are set forth in Section VII.

G. Fuel System Modification (Item F).

Modifications to the fuel system to provide positive fuel pressure during the maneuver were discussed with engine and fuel system specialists. The most feasible and economical fuel system modification would be the installation of a fuel accumulator of about five to seven gallons capacity. Suitable check valves and pressure valves would be included. A line from the compressor bleed air would provide the pressure air supply to charge the accumulator. A pressure operated valve would open and allow the accumulator supply to feed the engine when the main fuel supply pressure dropped to a predetermined point.

H. Electrical System

Modification of the existing electrical system will be dictated by the specific requirements of the zero-g experiments being performed.

Research of the Technical Orders reveals that the existing electrical system is composed of:

1 ea 400 amp 28 V.D.C. Generator

1 ea 6 Volt-Ampere Instrument Inverter

1 ea 750 Volt-Ampere (or 2500 VA) Inverter

1 ea 250 Volt-Ampere Standby Inverter

Additional generating capacity could be considered if necessary.

I. Zero Gravity Flight Instrumentation

The pilot's ability to maintain the aircraft in weightless state will be partly dependent on the cockpit instrumentation designed to indicate departures from the desired flight path. Medical research in zero gravity has produced

some improvements in zero-gravity flight indicator instruments; however, adequate instrumentation remains a major shortcoming.

The zero gravity indicator must present accurate real-time data to the pilot in immediately useable form. Many potential designs and human factors requirements were considered before arriving at the system shown diagramatically in Figure 7. The heart of the system is a pair of linear sensing accelerometers, fixed with respect to the aircraft. Accelerometer No. 1 detects linear acceleration along the vertical aircraft axis (Yaw axis). Accelerometer No. 2 detects linear acceleration along the longitudinal axis of the aircraft (Roll Axis), thus sensing the effects of engine thrust and aerodynamic drag.

The outputs of these two accelerometers are fed through the electronic systems as shown in the schematic. Basically, this electronic system: (1) records the zero gravity deviation versus time and, (2) presents an instantaneous readout to the pilot. The record may be used later to determine the particular time versus gravity parametric data for the experiments, and to provide an integrated quality "score" for the parabola. The instantaneous pilot scope presentation will be used as a flight direction aid during the performance of the maneuver.

The suggested display for this oscilloscope face is as follows. The scope has a single, permanent, horizontal center line and two vertical lines as shown in Figure 8 (A). During normal one-g flight (Hi-Range Mode), the bright line display will draw a single horizontal bright line at the top of the scopeface as shown by Figure 8 (B). This display remains until the g-load is reduced on maneuver entry down to + 0.5 g. At this point the zero-g flight display mode (Lo-Range Mode) appears and is brought down to center on the scope during zero-g flight. This zero-g presentation is as shown in Figure 8 (C). The bright line circle is centered on the horizontal line between the two vertical lines. Fore and aft linear acceleration is represented by the diameter of the circle, and is responsive directly to the throttle. Should the aircraft have a residual deceleration, the circle will be enlarged (and centered) as shown in Figure 8 (D). Corrective action will be throttle addition by the pilot. Conversely, a forward residual linear acceleration would be represented by a smaller diameter circle, and the throttle should be retarded to bring the circle back to zero-g diameter. The vertical position of the bright circle, center dot, and bright horizontal hash marks represents the zero-g deviation acceleration along the vertical aircraft axis. The bright line circle above the horizontal line would show a value of positive g-loading, and require increased pushover to effect return to zero-g. Negative g would be conversely represented by a below-the-horizontal bright circle, center dot, and bright horizontal hash marks.

This instrumentation gives a very simple, naturally correlated, instantaneous display to the pilot, which should be simple to follow with the lowest learning curve.

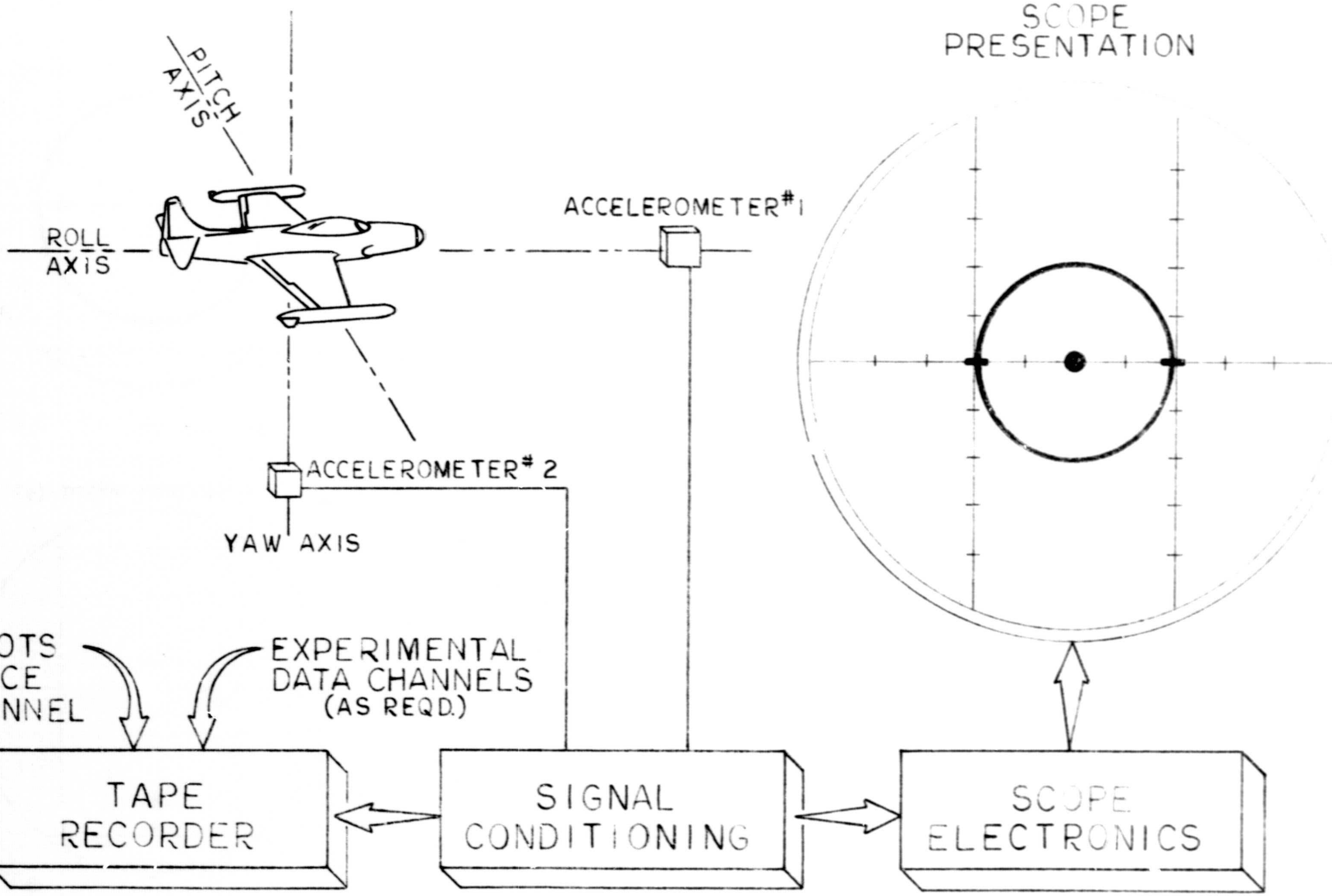
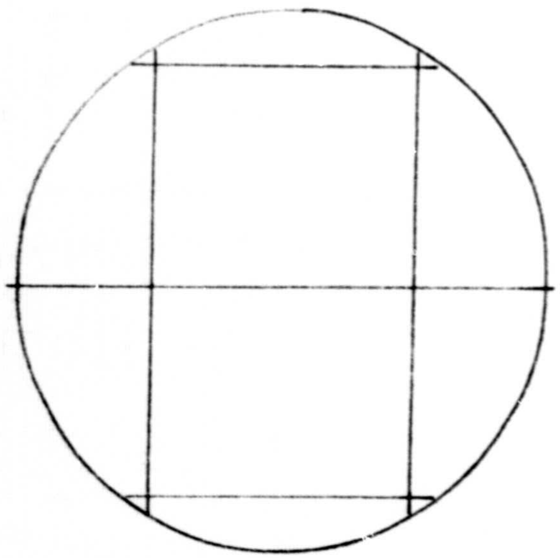
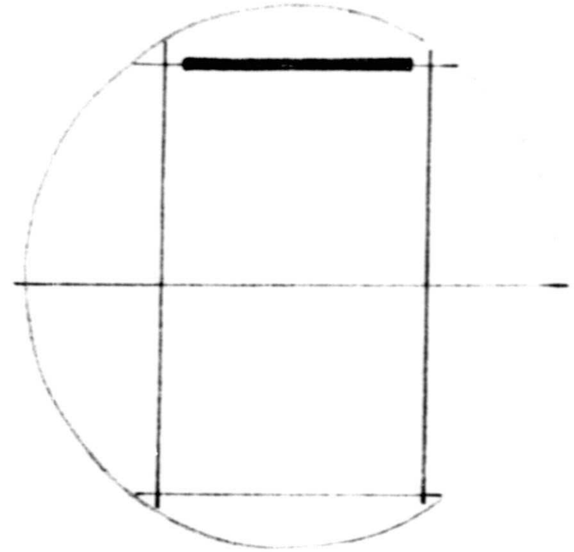


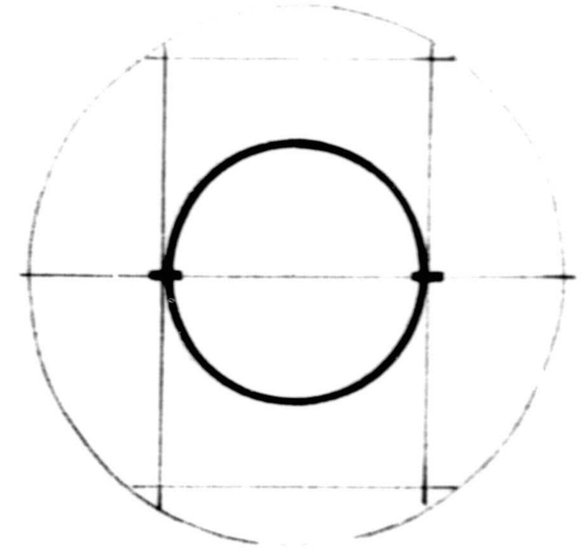
Figure 7. Proposed Zero-G Flight Instrumentation System



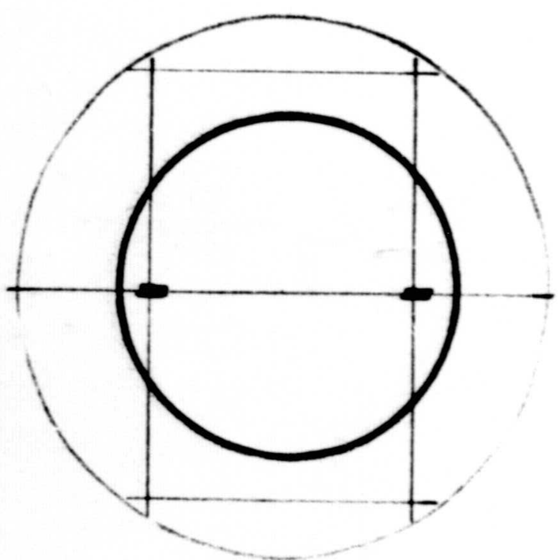
(A) Scope Graticule



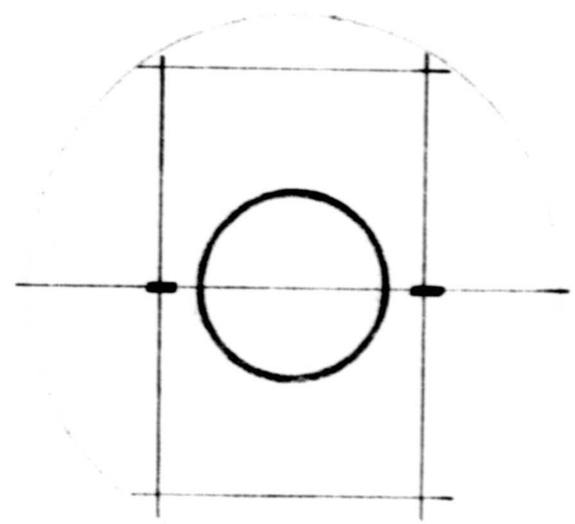
(B) HI-RANGE MODE
Vertical G = 1G Positive



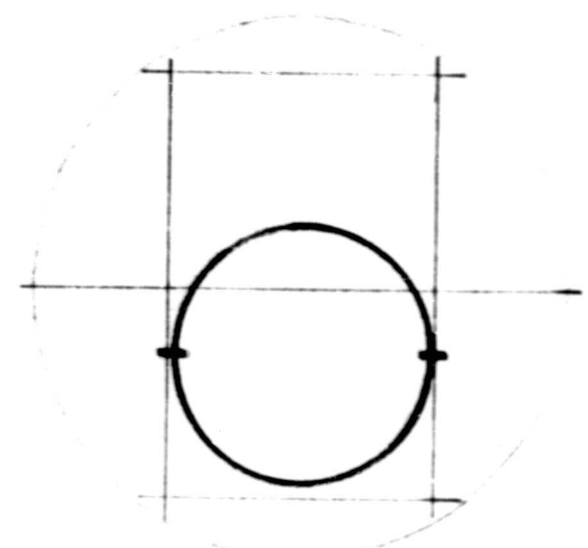
(C) LO-RANGE MODE
Vertical G = Zero
Longitudinal G = Zero



(D) LO-RANGE MODE
Vertical G = Zero
Longitudinal G = Negative



(E) LO-RANGE MODE
Vertical G = Zero
Longitudinal G = Positive



(F) LO-RANGE MODE
Vertical G = Negative
Longitudinal G = Zero

Figure 8. Typical Cockpit Presentations From Zero-G Instrumentation

SECTION VI. T-33 Aircraft Maintenance

It is assumed that this aircraft will be stationed at Redstone Arsenal Airfield. The minimum maintenance/operations crew will consist of 1 pilot & 2 crewmen. The crewmen would support normal preflight, flight, and postflight operations; this would include, reservicing and a light level of scheduled maintenance. The maintenance expected of this crew does not include: (1) operations on or set up of the experimental equipment, and (2) full range unscheduled maintenance. It is felt that such unscheduled maintenance could best be accomplished through a separate contract; a nearby location for this contracted maintenance would be an obvious advantage.

Redstone Airfield has jet fueling equipment, gaseous oxygen servicing, and T-33 DC-type aircraft starter equipment. An additional pickup truck equipped with heavy alternators and ARC-27 plus a VHF communications radio would be necessary. Additional equipment might be necessary depending on the availability for co-use of this equipment with other activities.

Maintenance parts support arrangements should be made with the USAF. The most satisfactory arrangement would be to use parts service from the nearest Air Force Base in Alabama, if this can be arranged.

SECTION VII. PILOT QUALIFICATIONS AND FAA AIRSPACE REQUIREMENTS

A. Pilot Qualifications

The primary objective of the zero-g program proposed herein is not flight qualification of hardware, but rather the development of engineering and scientific solutions to the problems of space manufacturing. Therefore, in selecting a primary support crew, first consideration should be given to their engineering and/or scientific backgrounds. Obviously, the pilot must be carefully selected, not only for his flying ability, but also for his engineering skills necessary to handle the type mission and equipment being flown.

The zero gravity mission itself is more exacting than most ordinary operational aircraft missions. In addition, the aircraft suggested (T-33, T-38, F-104) are first line jet fighter aircraft and require pilot skill and training specifically in this type aircraft. The basic pilot qualifications listed below should be used as a guide. The total and type of flight experience is necessary to insure that the pilots' awareness during the flight profile is sufficient to encompass the ordinary problems of take off, landing, safety of flight, etc, as well as the special nature of the parabolic zero-g maneuver; experience must also include an available reservoir of concentration that can be devoted to the experiment being accomplished.

The pilot must be considered a major part of the engineering/scientific talent being applied to the project.

The minimum pilot qualifications would include:

<u>Accumulated Flight Requirements</u>

500 hours in jet aircraft
500 hours in single engine aircraft
1500 hours total flight time

<u>F.A.A. Certificate Requirements</u>

The pilot should hold a current class FAA Medical Certificate in addition to an FAA Commercial Pilot Rating.

<u>Currency Requirements</u>

The pilot should be current in the type aircraft being used for zero-gravity operations.

(1) Initial Currency. To obtain currency on initial assignment, the pilot should be assigned to attend one of the USAF jet up-grading courses regularly held at Craig AFB, Alabama or Randolph, AFB, Texas. These courses consist of from 10 to 20 hours refresher jet flight with appropriate ground school and are held to reorient field grade officers who are being rotated from primary non-flying to primary flying assignments.

(2) Monthly Currency. The pilot should have flown at least 10 hours in the previous 60 days and have made at least 2 take offs and landings in the previous 30 days prior to conducting solo pilot zero-gravity operations.

(3) Yearly Proficiency. The yearly flight requirements should include at least 50 hours total time with at least 20 hours in the type aircraft being used for zero-gravity support.

The instrument currency requirement will depend on the necessity for utilizing IFR departures and approaches during zero-gravity missions and will add to the above proficiency should the operation require this type effort.

B. FAA Airspace Requirements

There should be no difficulties with respect to authority for operating within the normal FAA airspace framework. The operation may be conducted under Visual Flight Rules (VFR) in which the pilot will assure that he is both off the airways and outside the local Huntsville Control Zones. Under these rules the pilot is responsible for maintaining his own safe clearances. The flight may be conducted under Instrument Flight Rules (IFR) in which the FAA will direct the pilot in the air space and will provide flight clearance for other aircraft operating under IFR rules. Operation under IFR does not necessarily mean that flight conditions include weather operation. IFR conduct can be selected in clear weather if desired.

Normally zero-gravity test operations would be conducted in clear weather conditions. However, it would be proper to consider penetrating cloud cover on departure and approach. The recommendations for the actual parabolic maneuver are that it be accomplished in clear weather (VFR) conditions. There should be lateral cloud clearance of more than 2 miles to each part of the trajectory and any ceiling should be more than 2000 feet above the maximum height of the trajectory. Any lower cloud cover should be at least 5000 feet below the minimum altitude expected on pullout from the maneuver.

The Huntsville area is fortunate in that it is not a crowded airspace compared to many areas in the Eastern United States. Huntsville is situated in the Memphis air traffic control center area and it would be possible to set aside a time-of-use airspace should zero-gravity test operations become sufficiently regular to warrant such an airspace.

SECTION VIII. EXPERIMENT TEST POD

A. Design

All experiments would be designed to be carried out within the envelope of a test pod. The size and shape of the test pod would be determined by the configuration of test hardware for earth orbital flight experiments and limitations imposed by available area within the aircraft. Modifications of the nose compartment, wing tip tanks, second pilot's seat area, travel pod, and the development of a mid wing compartment could be accomplished to house the test pod and required auxiliary test equipment such as electrical power supply, vacuum source, pressure supply, instrumentation, and control mechanisms.

The test pod would have the capability of being readied in the shop and taken to the zero g simulator for testing.

B. Instrumentation

Visual data could be collected by means of video tape or motion picture film. The latter is recommended initially since it eliminates the need for on board recorders or telemetering equipment. Motion picture cameras of the type required are available through the Photo Lab and R-ME-MSI.

Test measurements could be recorded on board using a six channel tape recorder and analyzed after flight. If required, real time data could be sent by telemetry transmitter to a ground receiving station. Telemetry equipment is available through R-ME-MSI, however, a ground tracking antenna would be required to receive telemetered information. The cost of modifying a surplus antenna is estimated at $2,000.

Function sensors for anticipated measurements are available through R-ME-M.

Power modules and lighting would have to be provided or modified at an estimated cost of $5,000.

SECTION IX. PROPOSED EXPERIMENTS

Basic research, such as investigating the interaction between different liquids and liquids with solids where surface tension and viscosity are the main forces could be conducted in test pods within the aircraft.

Liquids, unlike solids and gases, do not behave the same in zero g as they do on earth. Since the magnitude of the weight of liquids on earth is many times that of their surface tension forces, only a few signs of the effects of surface tension are noticeable on earth. Mercury forming a convex surface in a tube and water forming a concave surface and even defying gravity by rising in a capillary tube are a couple examples of effects caused by surface tension.

In orbit, where liquids are weightless, the effects of surface tension no longer take a back seat to the weight. A quantity of liquid floating free in space will assume a spherical shape as fast as the liquids viscosity will allow. For water the time is on the order of magnitude of 0.7×10^4 CM/sec.

Several experiments have been performed on the behavior of liquid propellants in free fall so that an effective method to get the propellants to the rocket motors for restarting capability could be developed, but little or no work has been done with the behavior of liquids interacting or mixing with solids, gases, or other liquids.

How liquids that are brought into contact with a solid coats the entire surface of the object like water rising in a capillary tube, or runs off like mercury forming a spherical shape on glass will determine some of the things that may be done in space that can't be done on earth.

The behavior of liquids with solids will determine, to name a few, the feasibility of producing or developing: hollow or multilayered pressurized or unpressurized castings; pre-stiffened structural materials; high density single crystal growth, potentially as valuable as the development of transistors, and unsuccessfully produced on earth due to settling of solution; new refining and purification techniques which may enable us to economically produce some truly space age materials, the filament state of boron for example exhibits a strength greater than high strength steel with a weight 20% less than aluminum at a temperature that aluminum is melted. Extensive use of boron in jet engines could mean as much to the aircraft and space industries as the development of the jet engine and rocket motor.

How liquids behave with gases under different pressures will determine what can be done in this area. A quantity of liquid injected with a gas will form a hollow sphere due to surface tension, and by controlling the correct parameters, the molicules might be oriented as wished, as well as producing the desired interior pressure to produce new characteristics.

These spheres and microspheres are potentially valuable for composite ultra high strength to weight ratio structures, used in composites for deep dive submarines, tailored heat characteristics for uses in high and low temperature structures and bearings.

Liquid vapor pressure and free-fall behavior will determine the feasibility of new methods in manufacturing.

How liquids mix or coat each other will determine composite molding and forming processes, new physical and chemical properties in materials, and even new compounds and material characteristics may be developed.

Liquids do not behave the same in free-fall as solids and gases; however, solids can be dissolved or melted as they are in most refining processes, and gases can be liquified as in rocket fuel. It is therefore evident that liquid behavior in space is not limited to things which are liquid at room temperature.

Contributions could be made to the development of hardware and procedures for manufacturing space flight experiments by examining equipment and techniques under a simulated space environment prior to conducting the experiment in space. For example, methods of controlling contaminants such as fumes and soot from welding processes and chips from cutting processes could be developed and evaluated under zero gravity conditions.

The following is a list of proposed space flight experiments, now under development, that could be flown on the zero g test aircraft.

Tube Joining: The objective of this task is to study the effect of reduced gravity on capillary flow and surface wetting.

Electron Beam Melting: The objective of this task is to observe the effect of zero gravity on melted materials and then to examine the metallurgical characteristics of the resolidified materials to determine differences from similar materials resolidified in a 1 g environment.

Composite Structures: The objective of this task is to measure the distribution of elements of different densities that were mixed, melted, and resolidified in the zero g environment.

Single Crystal Refining: The objective of this task is to study the extent to which the absence of vibration and zero gravity during solidification of a material will affect the distribution and location of imperfections.

Metal Cutting: The objective of this task is to develop techniques and equipment for severing materials in space, to meet requirements such as the cutting of windows in the wet workshop. Chip collection techniques would have to be developed before this equipment could be readied for space flight.

SECTION X. T-33 AIRCRAFT MODIFICATION, MAINTENANCE, AND OPERATIONAL COSTS

Estimated costs associated with modifying, maintaining, and operating the T-33 aircraft for zero g experimental purposes are given in Tables II and III respectively.

MODIFICATION (REFER TO FIGURE 6)	ESTIMATED MATERIAL COST ($)	ESTIMATED DIRECT LABOR COST (Mhr's)	ESTIMATED TOTAL COST* ($)	APPROXIMATE EXPERIMENTAL VOLUME PRODUCED ($Ft.^3$)	ESTIMATED PAYLOAD CAPABILITY (Max) (Lbs.)
ITEM A (Nose Compartment)	$7500.00 (Total)	6400 Mhr's	$64000.00	3 $Ft.^3$	75 Lbs.
ITEM B (Wing Tip Pods)				29 $Ft.^3$ /Wing Tank	800 Lbs./Wing Tank
ITEM C (2nd Pilots [illegible]				20 $Ft.^3$	400 Lbs.
ITEM F (Fuel System)					
ITEM D (Baggage Carrier Pod)	800.00	2000 Mhr's	20,000.00	10 $Ft.^3$	300 Lbs.
ITEM E (Midwing Pylon Pod)	1700.00	2700 Mhr's	27,000.00	12 $FT.^3$ /Wing Pod	800 Lbs./Wing Pod

*Direct Labor, Overhead, G & A, and Fees.

TABLE II. ESTIMATED T-33 AIRCRAFT MODIFICATION COSTS AND RESULTANT PAYLOADS

Cost Items	Estimated Costs ($) Per Flying Hour*
Logistical Supplies (Fuel, Oil, GOX)	$56.50
Maintenance (Direct Labor & Parts)	$94.50
Flight & Ground Crews	——

*Estimates Based On Air Force and National Guard Statistics.

Table III. Estimated Operation & Maintenance Costs for T-33 Aircraft.

ITEM	ESTIMATED MATERIAL COST	ESTIMATED DIRECT LABOR COST	ESTIMATED TOTAL COST
Test Pods	$5,000	Manufacture In-House	$5,000
Instrumentation	$7,000	-	$7,000

TABLE IV.

Estimated Cost for Fabrication and Instrumentation of Experiment Test Pod (Minimum Requirements)

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